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Noble gas release signal as a precursor to fracture

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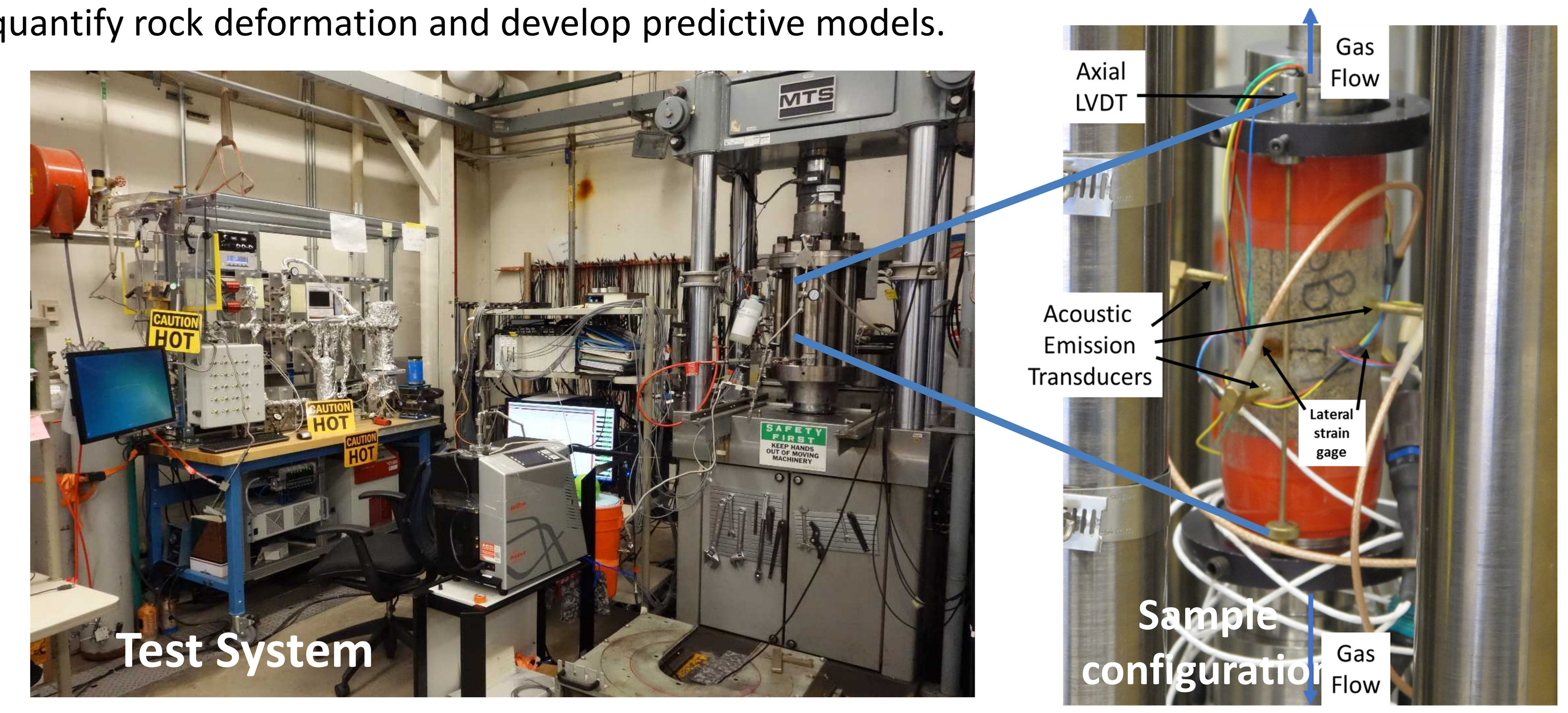
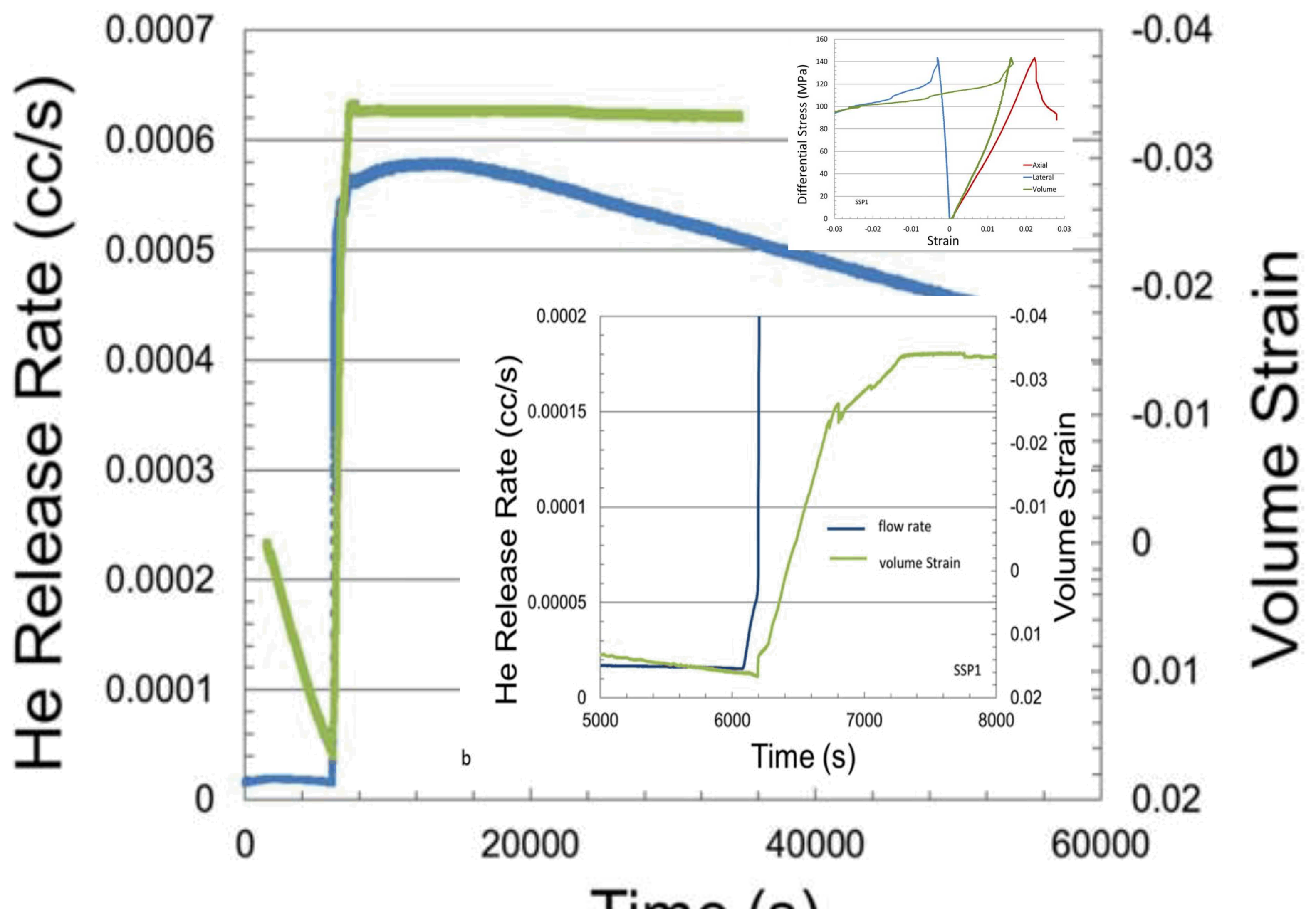
Hypothesis:

- **Noble gas release may be related to deformation state of rock**
- **Natural gas release may be used to signal deformation**

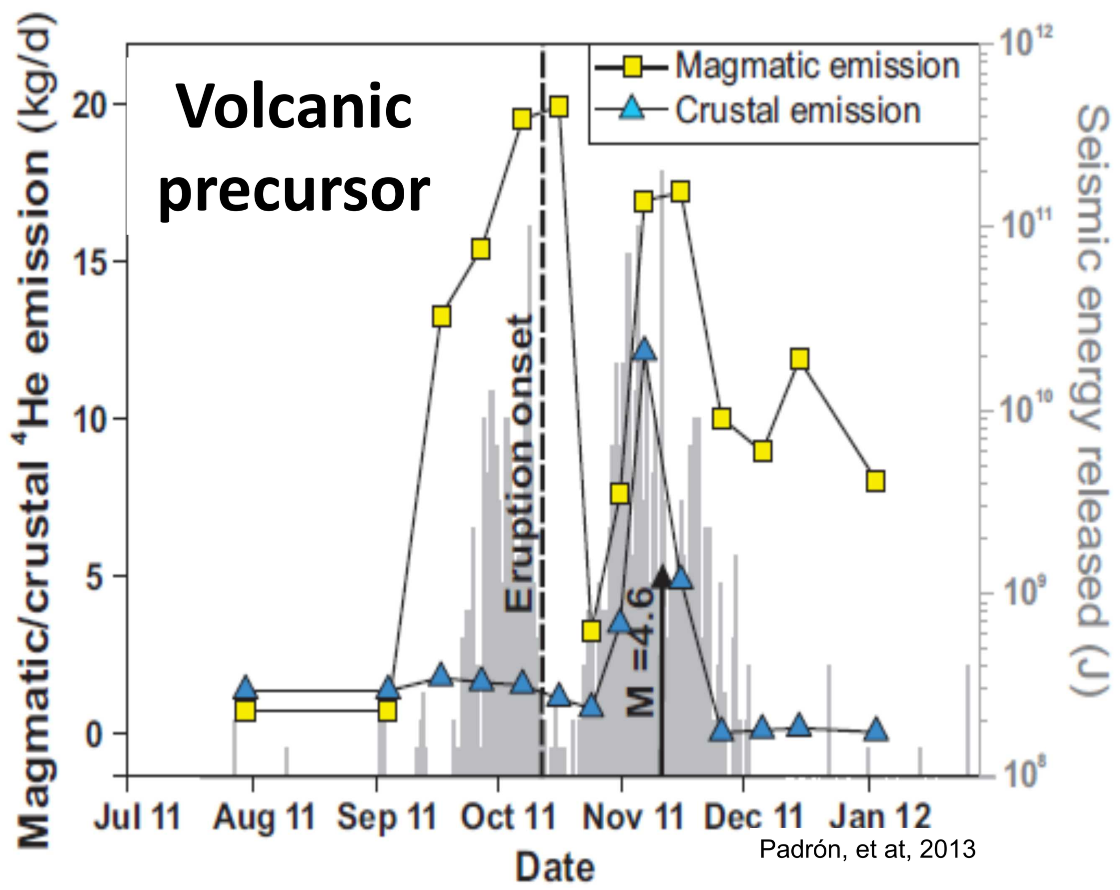
Abstract

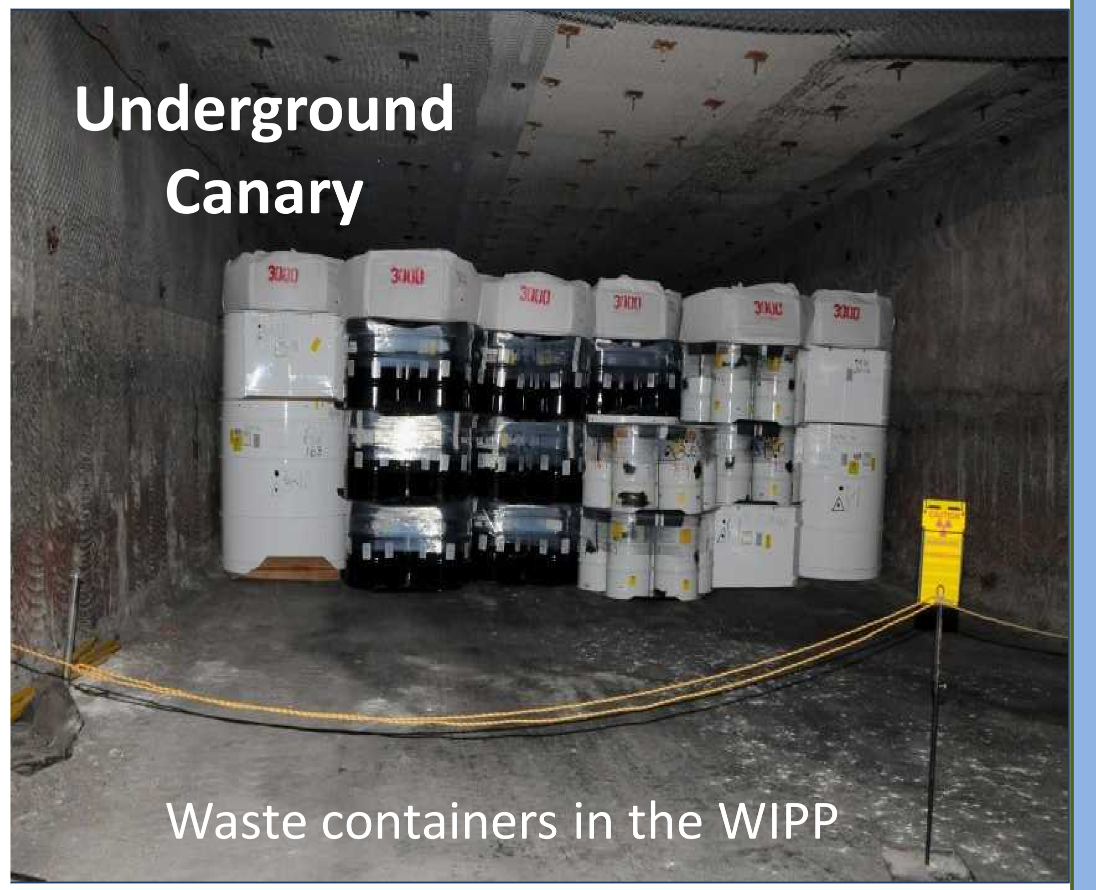
We present empirical results of rock strain, microfracturing, acoustic emissions, and noble gas release from laboratory triaxial experiments for a granite, basalt, shale and bedded rock salt. Noble gases are released and measured real-time during deformation using mass spectrometry. The gas release represents a precursive signal to macrofracture. Gas release is associated with increased acoustic emissions indicating that microfracturing is required to release gas and create pathways for the gas to be sensed. The gas released depends on initial gas content, pore structure and its evolution during deformation, the deformation amount, matrix permeability, deformation style and the stress/strain history. Gases are released from inter and intracrystalline sites; release rate increases as strain and microfracturing increases. The gas composition depends on lithology, geologic history and age, fluids present, and radioisotope concentrations that affect radiogenic noble gas isotope (e.g. 4He,40Ar) production. Noble gas emission and its relationship to crustal processes such as seismicity and volcanism, tectonic velocities, qualitative estimates of deep permeability, age dating of groundwater, and a signature of nuclear weapon detonation. Our result show that mechanical deformation of crustal materials is an important process controlling gas release from rocks and minerals, and should be considered in techniques which utilize gas release and/or accumulation. We propose using noble gas release to signal rock deformation in boreholes, mines and waste repositories. We postulate each rock exhibits a gas release signature which is microstructure, stress, strain, and/or permanent deformation dependent. Calibration of such relationships, for example relating gas release per rock unit volume to strain may be used to quantify rock deformation and develop predictive models.

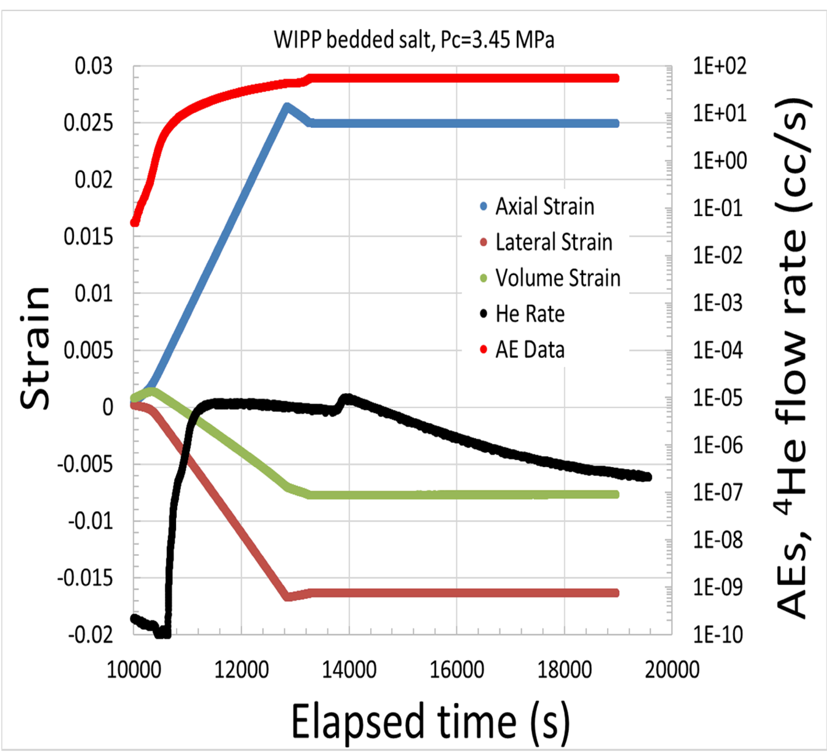


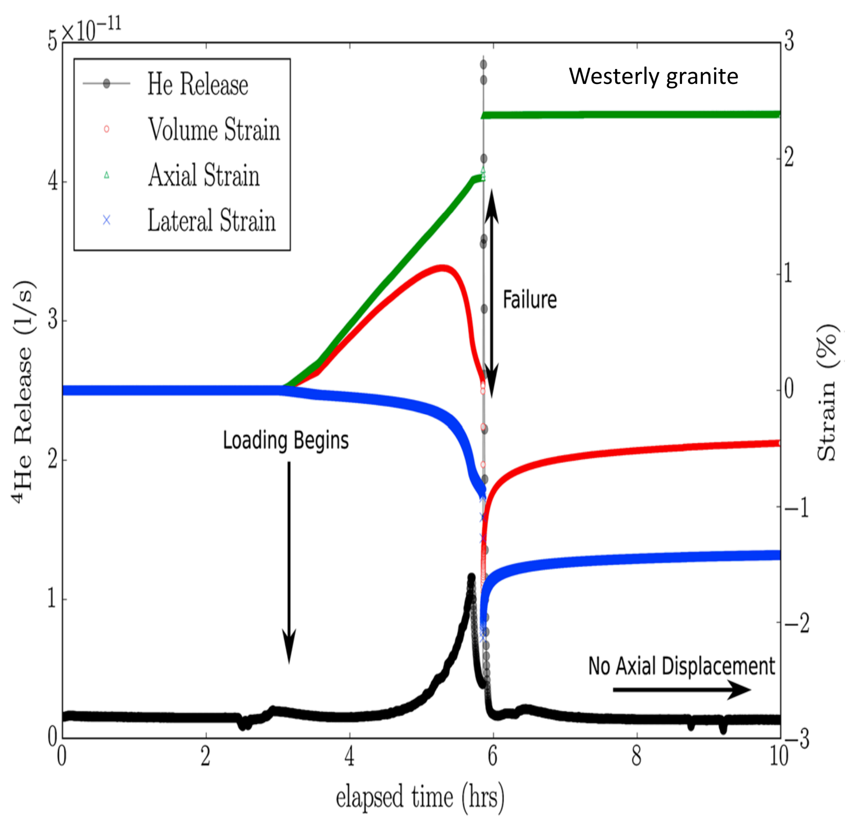


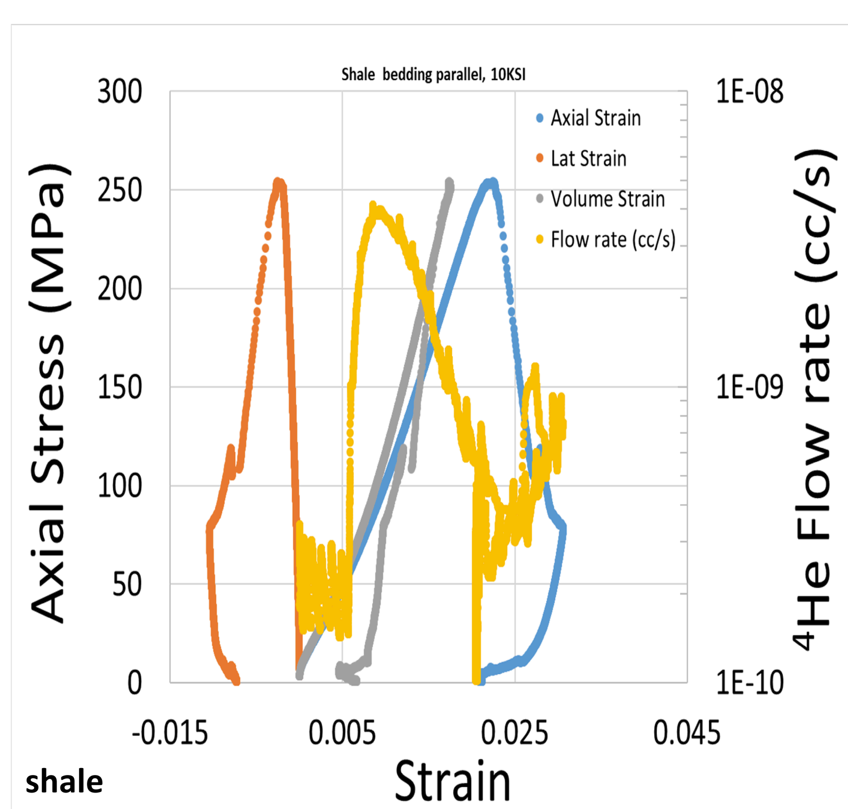
^{4}He release during shale deformation, ^{4}He introduced into pore structure prior to testing. Bauer et al 2016

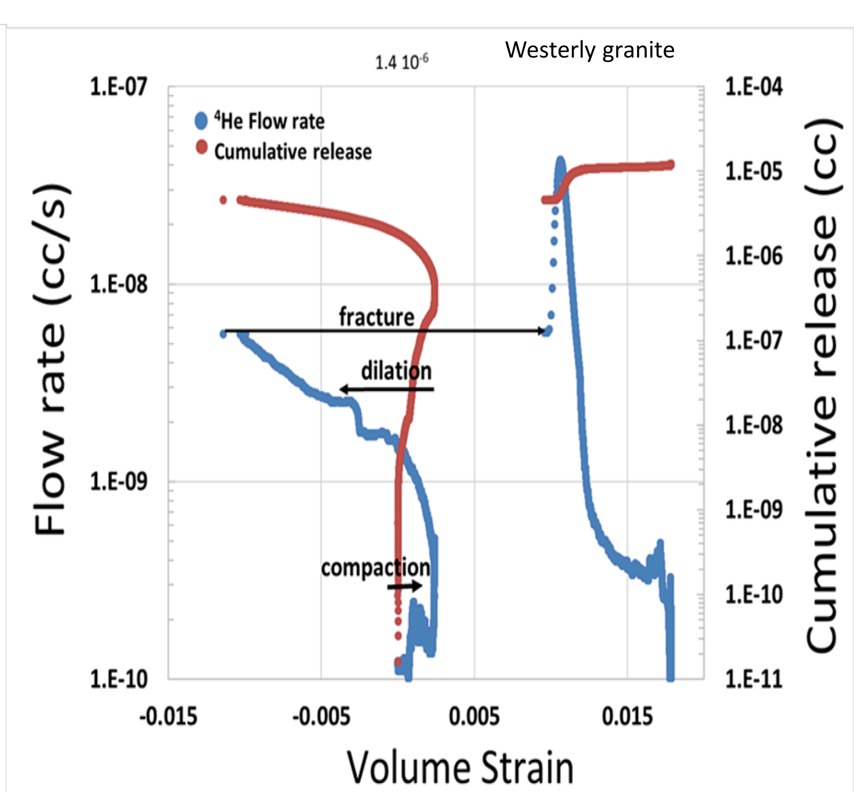


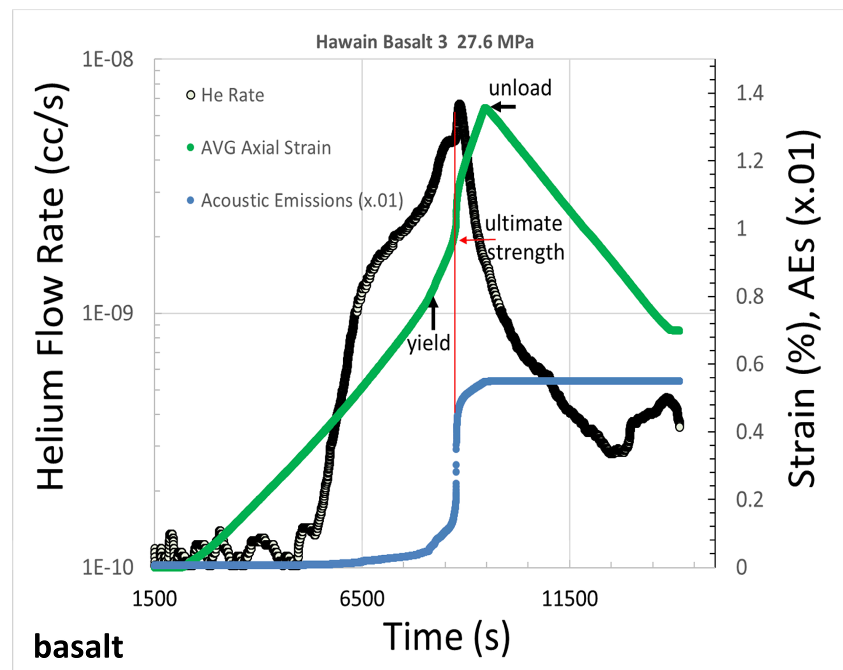


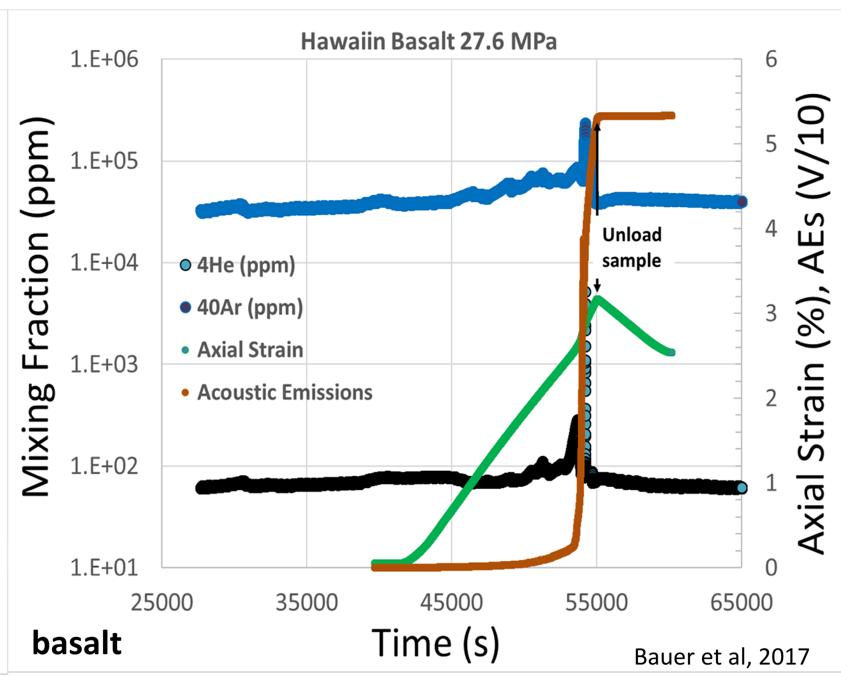










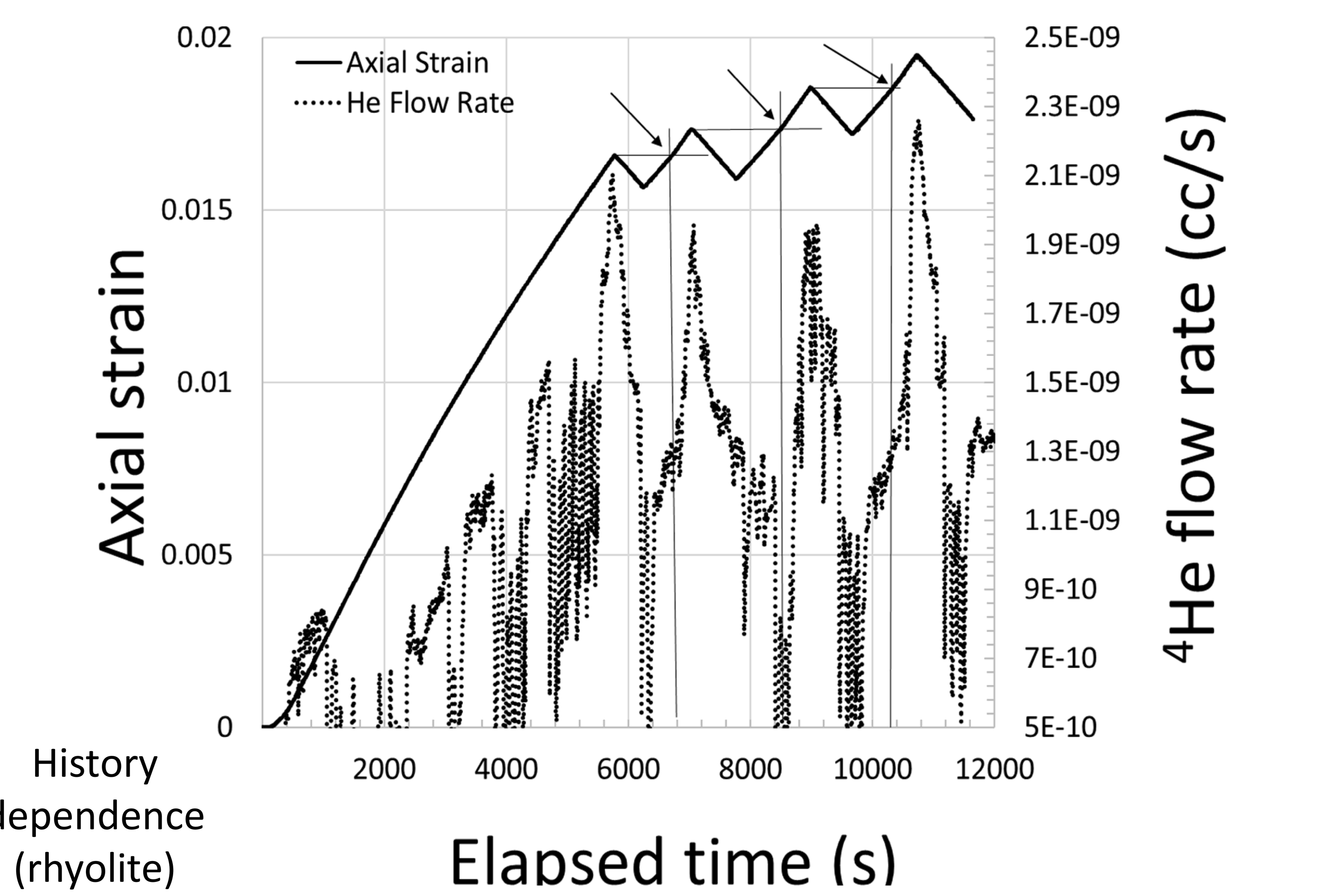


The residual gas analysis portion of the test system utilizes mass spectrometry, which measures the mass-to-charge ratio abundance of gas-phase ions. The mass spectrometer continually scans for gases during the deformation. We use two different mass spectrometers: a helium leak detector which measures the flow rate of mass 4 and a QMS capable of scanning the total abundance of gas over a broad mass range.

The helium leak detector is an Oerlikon Leibold Phoenix L300i, a specialized mass spectrometer, which detects only ^{4}He. It works in the mass range of 2, 3, 4 amu, with a minimum detectable leak rate in vacuum mode is $<5\times10^{-12}$ mbar l/s. Time constant of the leak rate signal is <1 s, and the filament is Iridium/Yttria-oxide. The analytical devices are semi-portable, on a rolling cart so that all triaxial frames in the lab are accessible.

The QMS is a Pfeiffer HiQuadTM , for analysis of neutral particles with a mass range from 1- 340 amu. The scan speed is 0.125 ms- 60 s/amu; typically full scan time for a suite of gases (10 species) is on the order of 1-2 seconds. The analyzer is a QMA 410, with a cross beam ion source and a detection limit at 1×10^{-15} mbar. The detector is SEV 217/Faraday, and the filament is tungsten. The maximum operating pressures are Faraday 10^{-4} mbar and SEM 10^{-5} mbar. The software which is used to operate the HiQuadTM is Quadera®, with a LabVIEW® based user interface for data acquisition and control.

The mechanical portion of the test system consists of a triaxial cell(s) in a variety of loading frames, with the capability of triaxial testing of cylindrical samples ranging in diameter from 2.5 cm in diameter (5 cm long) to 10 cm diameter (20-25 cm in length). The triaxial cells are capable of confining pressures to 400 MPa with sufficient axial force (stress) capabilities to fracture rock in compression/ extension. The mechanical test system has a pore fluid flow through capability used with high pressure to simulate pore pressure at depth and low pressure (in the present application of high vacuum).



History dependence (rhyolite)

Bauer, 2017

Results, observed in various lithologies

1-Gases are released and measured real time during deformation

2-Gas release signal is precursive to macrofracture

3-Gas released (mass, composition, etc.) depends on initial gas content, pore structure and its evolution during deformation, deformation amount, permeability

4-Release rate increases as strain and microfracturing increase

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References

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SAND2017-XXXXX C. Frank Trusdell , USGS, HVO, collected and provided Basalt samples